COMPARISON OF GOME-2 AND OMI SULFUR DIOXIDE RETRIEVALS

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ABSTRACT

The US algorithms for retrieval of sulfur dioxide column amounts from OMI UV radiance data have been applied to GOME-2 data. The OMSO2 algorithms use four assumed SO_2 layer heights to derive total column SO_2 for typical emission conditions ranging from anthropogenic sources, to smelter emissions and volcanic degassing, to effusive volcanic eruptions, and finally to explosive volcanic eruptions. The GOME-2 and OMI SO_2 results were compared under background, passive degassing, and explosive volcanic cloud conditions. Preliminary results indicate that the GOME-2 SO_2 background retrieval noise level is twice that of OMI. For high column amounts of SO_2 in stratospheric volcanic clouds, the GOME-2 peak amounts and total cloud masses are about two-thirds of the OMI amounts. The effect of spectral bandwidth differences is being considered as one of the causes of these discrepancies.

INTRODUCTION

Sulfur dioxide is a transient constituent in the atmosphere as once released, it converts to sulfate, especially rapidly at low altitudes and in moist environments. Thus, background levels are generally below detection limits from satellite platforms. However, amounts can be very large near volcanic sources, exceeding 1000 Dobson Units (DU) in very fresh eruption columns, while anthropogenic sources, such as smelters and coal-fired power plants, are far weaker, producing column amounts from less than 0.1 DU to about 2 DU. The dynamic range extends over four orders of magnitude, posing a challenge for any algorithm or group of algorithms. In this study we are comparing instrument performance to assure a consistent data base for geophysical analysis. The US OMI Science Team SO_2 algorithms [1, 2, 3] are used to compare retrievals from both instruments for a range of geophysical conditions. The OMSO2 code uses two different algorithms to achieve a dynamic range of 3 orders of magnitude. An off-line iterative algorithm is required for a 4th order of magnitude. All algorithms compare observed radiances with calculations from a full radiative transfer model to assure that all the physics is included.

In a recent comparison of GOME-2 and SCIAMACHY DOAS SO_2 retrievals [4] from the August 2008 Kasatochi eruption clouds, the peak SCIAMACHY values were about 25% greater than GOME-2 peak values. Possible explanations were that different temperatures were used for the SO_2 cross sections and the irradiance data were selected differently.

In this study we compare OMI and GOME-2 data from the Kasatochi eruption, the June 2009 Sarychev eruption, and from strong degassing from the Kilauea volcano on Hawaii, also in June 2009. In addition, the background noise levels are compared to determine the threshold for detection of emissions.

1. OMI and GOME-2 ORBIT CHARACTERISTICS

OMI on EOS Aura platform and GOME-2 on the MetOp A spacecraft fly in different orbit planes separated by about 3 hours in local time. In addition, OMI's orbit has a daytime ascending node while GOME-2 has a night time ascending node thus making the separation time dependent on latitude. As volcanic clouds are always dynamic, no direct pixel to pixel comparisons are possible as was done with SCIAMACHY and GOME-2 in the same orbit plane but differing in time by about 40 minutes. We have elected to compare peak values and total SO_2 mass in the clouds, parameters that should change slowly with time.

2. BACKGROUND NOISE LEVEL COMPARISON

The smallest detectable SO_2 cloud mass depends on the retrieval noise level. The Total Ozone Mapping Spectrometer (TOMS) instrument had six fixed wavelength bands that were selected for ozone retrievals. Unfortunately, they were not optimum for discriminating SO_2 absorption from O_3 absorption and the background noise standard deviation of about 5 DU permitted detection only of volcanic eruption clouds [5]. The OMI Band Residual Difference and Linear Fit algorithms make use of optimum wavelengths that reduce the noise by a factor of twenty. This permits observation of passive degassing and air pollution emissions, including smelter plumes. The plume altitude must be specified using typical altitudes of 15 km for explosive eruptions, 5 km for effusive eruptions, 3 km for passive degassing, and 0 – 2 km for air pollution. Thus, achievement of low noise is crucial for long term monitoring of these emissions from operational satellites.

Two southern hemisphere orbits in August 2008 were selected to compare the noise levels. Fig. 1 shows the noise, in DU, vs solar zenith angle.

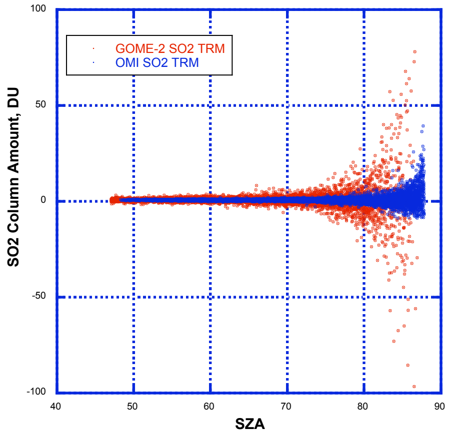

Figure 1. Background noise for 5km height retrievals in the southern hemisphere from GOME-2 orbit 9354 (red) and OMI orbit 21627 (blue) in August 2008.

It is clear that the GOME-2 noise (red) grows far more rapidly than OMI noise (blue) as the terminator approaches. In fact, the useful limits are about 70 deg for GOME-2 and about 80 deg for OMI. At low latitudes the noise levels for 15 km retrievals are 0.15 DU for OMI and 0.36 DU for GOME-2. The reason for the higher GOME-2 noise is undoubtedly because of deteriorating signal/noise ratios at wavelengths less than 320 nm in Band 2. If five wavelength channels are binned the noise is reduced to 0.2 DU.

3. LARGE VOLCANIC EVENTS

Four large volcanic eruptions in the past year have provided good cases for comparison. The largest was the August 7, 2008 eruption of Kasatochi in the Aleutian Islands which produced 1.3 Tg of SO_2 in a 12 km high cloud. The second largest, Sarychev in the Kurile Islands, erupted about 1 Tg of SO_2 in a series of eruptive pulses beginning on June 11, 2009. Days for comparison were selected for good coverage of the entire cloud in single orbit swaths, and to cover a range of peak SO_2 column amounts.

3.1. Kasatochi eruption cloud, August 2008

The August 9 Kasatochi cloud was selected for analysis because the entire plume was contained within single orbit swaths of both instruments (Fig. 2).

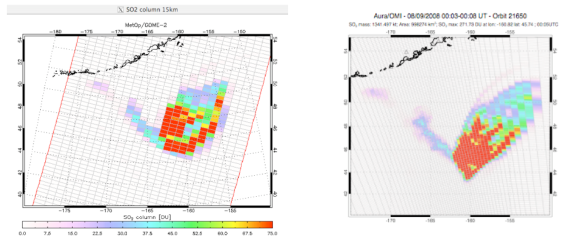

Figure 2. GOME-2 (left) and OMI (right) images of Kasatochi SO_2 cloud on August 9, 2008.

The cloud was observed first by GOME-2, followed some 3 hours later by OMI. Peak SO_2 values were 270 DU for OMI and 200 DU for GOME-2 as shown in Fig. 3. Generally, column values decrease with time as the cloud is sheared and *SO_2* is converted to sulfate, thus widening the discrepancy.

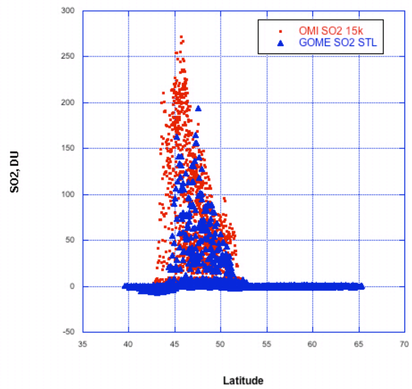

Figure 3. Scatter plot of SO_2 column values vs. latitude in August 9 Kasatochi cloud. Red points are from OMI, blue points are from GOME-2.

The total SO_2 mass in the cloud was 1.3 Tg for OMI, 0.87 Tg for GOME-2, a ratio of 0.67. This 33% difference is consistent with the 26% difference in peak values. The mass measurement is a more robust comparison than peak values.

3.2 Sarychev eruption cloud, June 2009

A second comparison was made using the June 11, 2009 eruption of Sarychev volcano in the Kurile Islands. This eruption continued for several days and emitted about 1 Tg of SO_2 in a series of small eruptions. On June 13 the eruption cloud was contained in single orbit swaths for both satellites. Fig. 4 illustrates the plumes observed by OMI and GOME-2.

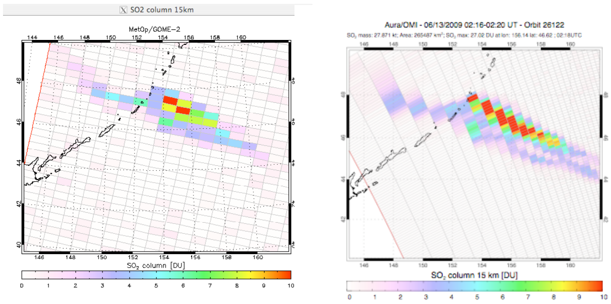

Figure 4. GOME-2 (left) and OMI (right) images of Sarychev SO_2 cloud on June 13, 2009.

The cloud on June 13 was small compared with Kasatochi's single large cloud and the peak SO_2 values were correspondingly smaller. OMI's peak was 27 DU while GOME-2 found 17 DU, a ratio of 0.63. The corresponding mass values were 0.028 Tg for OMI and 0.018 Tg for GOME-2, a ratio of 0.68. This retrieval difference is almost identical to that found in the Kasatochi cloud even with a ten-fold difference in cloud mass.

4. Volcanic degassing: Kilauea

The final comparison is for detection of degassing volcanoes, where the column amounts are generally less than 2 DU, but occasionally reach 10 DU. Kilauea volcano in Hawaii has a recent extended episode of strong degassing that has been monitored with OMI. An example selected for comparison is June 11, 2009, when a strong plume is carried WSW in the trade winds. The OMI image is shown in Fig 5 while the GOME-2 image for the same day is in Fig 6. The 3 km (TRL) profile is selected in both cases. The same geographic area is used and it is clear that the OMI near-nadir ground resolution provides a clear view of the plume. Although the GOME – 2 orbit is centered west of the island, the constant ground resolution of 40 x 80 km is inadequate to delineate the plume clearly with only a suggestion of enhanced SO_2 in the area.

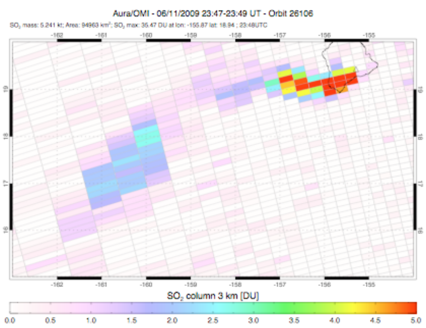

Figure 5. The SO_2 plume from Kilauea volcano in Hawaii on June 11, 2009 viewed by OMI contains 5.1 kt SO_2.

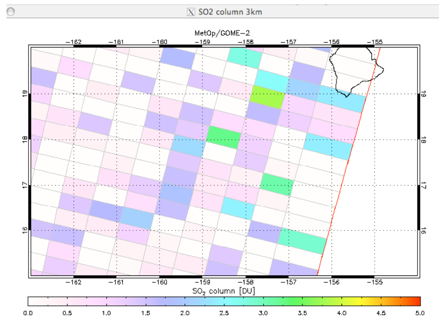

Figure 6. The GOME – 2 image of SO_2 from Kilauea volcano in Hawaii on June 11, 2009 corresponding to the OMI image in Fig 5.

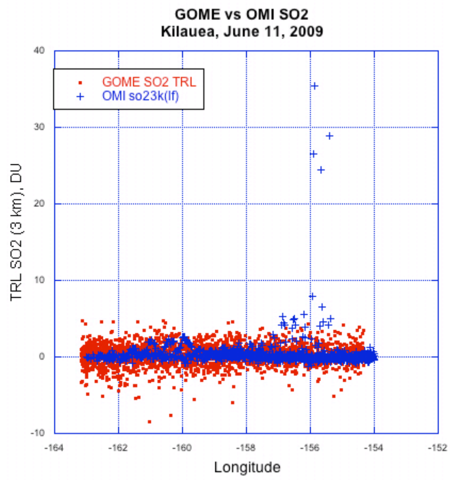

Figure 7. Pixel values of SO_2 from OMI (blue) and GOME – 2 (red) as a function of latitude for all pixels in Fig 5 and 6.

The peak OMI pixels are near 35 DU while none of the GOME – 2 pixels are outside the background noise as shown in Fig 7. The total tonnage in the OMI data is 5.2 kt while the GOME tonnage was not computed because the cloud boundaries are not discernable. DOAS retrievals from DLR show the plume somewhat better due perhaps to use of longer wavelengths and lower noise.

5. Comparison of minimum detectable plumes

The smallest quantity of SO_2 that can be detected is determined by the retrieval noise level and the footprint area.

While all of the UV sensors can detect the large column amounts in volcanic eruption clouds, other sources are responsible for most of the SO_2 input to the atmosphere. These sources include passive volcanic degassing, sulfate ore smelters, and coal-fired power plants. None produce the high concentrations of SO_2 in eruptions but they are widespread and usually operate continuously over the entire year. They emit into the lowest atmosphere where conversion to sulfate is rapid and detection is difficult due to low air mass factors. Thus, the highest sensitivity (lowest noise) is necessary for monitoring these sources. A comparison of the minimum detected plume from TOMS [5], OMI, and GOME –2 is presented in Table 1.

	Nimbus 7 TOMS	EOS Aura OMI	MetOP GOME-2
Nadir footprint (km) Scenes/scan	50 x 50 35	13 x 24 60	80 x 40 24
Spectral resolution (nm)	1.1	0.45	0.27
Spectral bands Wavelength span, nm	6 discrete bands 312.5 – 380	UV- 2 310 – 365	UV – 2 311 – 403
SO_2 retrieval noise, 1σ (DU) for 15 km cloud	5	0.15	0.36
SO_2 detection limit (tons) 5 adjacent pixels > 5σ	7000	26	650

Table 1. Comparison of detection limits from TOMS, OMI, and GOME-2 based on footprint size and background noise levels. OMI represents a huge advance over TOMS while GOME-2 is a more modest gain

A 33-fold increase in sensitivity of OMI over TOMS permits longer tracking of volcanic clouds as they dissipate and daily monitoring of degassing, smelters and air pollution. The GOME –2 noise is twice OMI's noise level and the nadir footprint is 25 times larger. The footprint difference is reduced at large scan angles due to GOME's constant footprint.

6. Conclusions

A long record of volcanic eruption masses was collected by the TOMS instrument beginning in 1978, and continued with OMI data beginning in 2004. This climate data record will be continued with GOME – 2 and future operational satellite sensors. Therefore, it is essential that the retrieval quality and calibrations are comparable. In addition, the increased sensitivity from use of optimum wavelengths available from hyperspectral instruments expands the range of observations with OMI to include passive degassing, smelters, and air pollution SO_2. This extends the data record to include a far larger fraction of the total SO_2 emissions that can now be monitored.

GOME-2 retrievals are 65% of OMI retrievals for moderate and large SO_2 amounts in volcanic eruptions. This difference persists relative to other UV instruments including SCIAMACHY [4] and must be understood and reconciled for an extension of the eruption record into the next decade.

The GOME-2 noise is twice OMI noise in background areas. This significantly limits the detection of anthropogenic sources and the monitoring of air pollution.

The GOME-2 minimum plume detection limit is 25 times the OMI limit at nadir. If the Hawaiian degassing case shown in Figures 5 and 6 is typical, then monitoring of volcanic degassing will be compromised although the use of longer wavelengths for better signal/noise ratio appears to improve the detections.

The causes of the higher GOME-2 noise and lower SO_2 calibration are not clear at this time. Factors such as spectral bandpass and stray light will be reviewed.

References

1. Krotkov, N.A., S.A. Carn, A.J. Krueger, P.K. Bhartia, and K. Yang (2006), Band residual difference algorithm for retrieval of SO2 from the Aura Ozone Monitoring Instrument (OMI), *IEEE T. Geosci. Remote Sens*., 44(5), 1259–1266, doi:10.1109/TGRS.2005.861932.
2. Yang, K., N. A. Krotkov, A. J. Krueger, S. A. Carn, P. K. Bhartia, and P. F. Levelt (2007), Retrieval of large volcanic SO2 columns from the Aura Ozone Monitoring Instrument: Comparison and limitations, *J. Geophys. Res*., 112, D24S43, doi:10.1029/2007JD008825.
3. Yang, K., N. A. Krotkov, A. J. Krueger, S. A. Carn, P. K. Bhartia, and P. F. Levelt (2009), Improving retrieval of volcanic sulfur dioxide from backscattered UV satellite observations, *Geophys. Res. Lett.,* 36, L03102, doi:10.1029/2008GL036036.
4. van Geffen, J., M. van Roozendael, M. Rix, and P. Valks, (2008), Initial validation of GOME-2 GEP 4.2: SO2 total columns (OTO/SO2) – ORR B. *Eumetsat TN-IASB-GOME2_O3MSAF-SOw-01.1*, 4 November 2008.
5. Krueger, A.J.,Walter, L.S., Bhartia, P.K., Schnetzler, C.C., Krotkov, N.A., Sprod, I., Bluth, G.J.S., 1995. Volcanic sulfur dioxide measurements from the Total Ozone Mapping Spectrometer (TOMS) Instruments. *J. Geophys. Res*. 100, 14,057–14,076.